ApJ Letter (accepted)
Preprint typeset using LaTeX style emulateapj v. 12/14/05

UNUSUAL LONG AND LUMINOUS OPTICAL TRANSIENT IN THE SUBARU DEEP FIELD

Yuji Urata[1], Patrick P.Tsai[1], Kuiyun Huang[2], Tomoki Morokuma[3], Naoki Yasuda[4] Masaomi Tanaka[5], Kentaro Motohara[3], Masao Hayashi[5], Nobunari Kashikawa[5], Chun Ly[6,7] and Matthew A.Malkan[8]

ApJ Letter (accepted)

ABSTRACT

We present observations of SDF-05M05, an unusual optical transient discovered in the Subaru Deep Field (SDF). The duration of the transient is $>\sim$ 800 d in the observer frame, and the maximum brightness during observation reached approximately 23 mag in the i' and z' bands. The faint host galaxy is clearly identified in all 5 optical bands of the deep SDF images. The photometric redshift of the host yields $z \sim 0.6$ and the corresponding absolute magnitude at maximum is ~ -20. This implies that this event shone with an absolute magnitude brighter than -19 mag for approximately 300 d in the rest frame, which is significantly longer than a typical supernova and ultra-luminous supernova. The total radiated energy during our observation was 1×10^{51} erg. The light curves and color evolution are marginally consistent with some of luminous IIn supernova. We suggest that the transient may be a unique and peculiar supernova at intermediate redshift.

Subject headings: supernovae:general

1. INTRODUCTION

Time-domain surveys in various wavelengths have been making mysterious new transients discoveries. These results are remarkable, and newly discovered transients are revolutionizing our knowledge of astronomy and astrophysics. The hard X-ray survey of *Swift* and related multi wavelength follow-ups found one unusual transient to be the tidal disruption of a star by a dormant super massive black hole (Bloom et al. 2011; Burrows et al. 2011; Levan et al. 2011; Zauderer et al. 2011). This discovery confirmed tidal disruption events as actual stellar phenomena. Other candidates for tidal disruption flares have been reported by optical imaging surveys (Gezari et al. 2009a, 2012; Drake et al. 2011; van Velzen et al. 2011; Cenko et al. 2012). Optical untargeted imaging surveys have also been discovering new stellar explosions. The discovery of SN2007bi has provided possibly the first evidence of pair-instability supernova (SNe), which are thought to be triggered by very massive stars (Gal-Yam et al. 2009). Ultra-luminous SNe are another recent discoveries (Barbary et al. 2009; Quimby et al. 2011; Pastorello et al. 2010). These transients are characterized by high optical luminosities reaching peak absolute magnitudes of -21 to -23. Because of their luminosity, they could possibly be detected with an 8-m class telescope even at higher redshift such as $z \sim 4$ (Quimby et al. 2011; Tanaka et al. 2012).

Several other optical transients are theoretically predicted but have not yet been observationally confirmed. One of them is an orphan GRB afterglow that is thought to arise as a natural consequence of GRB jets (Rhoads 2001; Totani & Panaitescu 2002). However, because of the limited sensitivity of current optical equipment, there is no promising candidate of orphan GRB yet. To extend the redshift frontiers of these transients and to search for transients undetected by optical surveys, we performed systematic transient searches and classification using a deep survey conducted by Subaru/Suprime-Cam. In this letter, we report the discovery of an unusually luminous long-duration optical transient. Throughout this paper, magnitudes are in the AB system.

[1] Institute of Astronomy, National Central University, Chung-Li 32054, Taiwan, urata@astro.ncu.edu.tw
[2] Academia Sinica Institute of Astronomy and Astrophysics, Taipei 106, Taiwan
[3] Institute of Astronomy, Graduate School of Science, University of Tokyo, Mitaka, Tokyo 181-0015, Japan
[4] Institute for the Physics and Mathematics of the Universe, University of Tokyo, Kashiwa 277-8568, Japan
[5] Optical and Infrared Astronomy Division, National Astronomical Observatory, Mitaka, Tokyo 181-8588, Japan
[6] Space Telescope Science Institute, Baltimore, MD, USA
[7] Giacconi Fellow.
[8] Department of Physics and Astronomy, UCLA, Box 951547, Los Angeles, CA, USA

2. SUBARU DEEP FIELD OBSERVATIONS

We obtained available optical imaging data sets of the Subaru Deep Field (SDF; Kashikawa et al. (2004); Ly et al. (2011)). The original SDF survey was conducted from 2002 to 2003 with 5 broad-band filters–B, V, R, i', and z'– and two narrow-band filters, NB816 and NB921 using the Suprime-Cam attached to the Subaru telescope. The 3 σ limiting magnitudes of the final stacked images reach B =28.45, V =27.74, R =27.80, i'=27.43, and z'=26.62, respectively (Kashikawa et al. 2004). The field was also monitored using the same camera before and after the SDF survey for various purpose with several programs. The total temporal coverage is $\sim$ 2630 d from 2001 to 2008. Although the observations for B and V were made by a single-epoch observation, multi-epoch data are available for R, i', and z' bands. These were particularly suitable for the transient survey. This field was also observed in U-band by the KPNO Mayall 4 meter telescope (Ly et al. 2011), near-infrared by UKIRT (Hayashi et al. 2009; Motohara et al. 2008) and ultraviolet by GALEX (Ly et al. 2009). These multi-wavelength data sets were crucial for constraining the SED of the transients and/or their host galaxies.

3. ANALYSIS AND RESULTS

The basic reduction of the Suprime-Cam data was performed using the SDFRED (Ouchi et al. 2004). To

discover the transients and variable objects, we made nightly stacked images for *Rc*, i', and z'. For these 3 bands, differential images were also generated with special-purpose software tuned to the Subaru/Suprim-Cam data and based on an algorithm in Alard & Lupton (1998). Figure 1 shows the optical transient found in images taken on 5 March 2005 at RA= $13^{\mathrm{h}}23^{\mathrm{m}}52^{\mathrm{s}}.76$ and Dec= $+27°43'58".84$. The SDSS serendipitously-detected this transient and lists it as a stellar-like object. We investigated available SDSS images taken on 18 January 2005 with u', g', r', i', and z' band filters. As in the SDF photometry, we measured the magnitudes in the r', i', and z' bands on these images. There were marginal detections in the g' and r' bands. This SDSS observation is the first time this object has been reported in this position. Hereafter, we define 18 January 2005 as the starting point of the transient (T_0). Figure 2 shows light curves for this transient with R, i' and z' bands. There is no significant variability between March 2001 and April 2003. The amplitude of the event was about 3.4 mag and the transient faded out until June 2008. Although the light curves have no temporal coverage for the brightening period, the duration of the transient is approximately 800 d, which is significantly longer than that for typical Ia, Ib/c and IIp SNe.

The host galaxy of the transient was identified using the deep-stacked B- and V-band images generated by Kashikawa et al. (2004). We also made deep-stack images for the *Rc*, i', and z' bands using images taken before 5 March 2005 to exclude the transient component. As shown in Figure 1, the host galaxy of the transient is discernible in all 5 bands. We also confirmed that the source is significantly extended, compared to the size of the point spread function. By comparing the positions of nearby stars in our reference frame with the image in which transient was discovered, we are able to align the images with accuracy of 0".07 rms. With an observed offset between the transient and the host galaxy of $\delta R.A. = +0".15$ and $\delta Dec. = -0".24$, the likelihood of a nuclear origin for the transient is only 0.03%. These deep images also allowed us to measure the brightness of the host galaxy accurately. Based on the publicly released SDF catalog, we made a photometric calibration and performed aperture photometry for the host galaxy using a 2" radius that was the same as that used for the SDF catalog. Although the very deep U-band and NUV (175-275 nm) images are available for this field, there is no counterpart at the position. The 3σ limits are 26.8 in U-band and ~ 27 mag in NUV, respectively.

We estimated a photometric redshift of the host galaxy using Hyper-Z (Bolzonella et al. 2000) code. The best-fitting result is $z = 0.65^{+0.02}_{-0.03}$ with reduced χ^2 of 1.02 using the burst template (age of 0.13 Gyr and the intrinsic extinction A_V of 0.2 mag). The 3-sigma error range is 0.50-0.70. Figure 3 shows the best-fitting model with actual measurements. The age of the host tends to be about 1.5∼2 times older than those of GRB host galaxies (Christensen et al. 2004). We also estimated the photometric redshift by using only the templates from Coleman, Wu & Weedman (1980, hereafter CWW). In this case, the best-fitting galaxy is irregular, and the redshift estimation is $z = 0.62^{+0.02}_{-0.02}$ with a reduced χ^2 of 1.19. In both cases, the values are in agreement as $z \sim 0.6$. With this photometric redshift, the peak absolute magnitude of this transient is estimated to be $M_R \sim -20$ mag, which is 2-3 magnitudes brighter than bright core-collapse SNe. Even at the lower limit of redshift, the peak absolute magnitude is still $M_R \sim -19.3$ mag. Assuming no bolometric correction, the total integrated optical output from SDF-05M05 during the observations (∼850 days) was $\sim 1 \times 10^{51}$ erg, which is comparable with those of GRBs (Urata et al. 2012, 2009; Huang et al. 2012). The absolute host magnitude was also calculated as $M_{\mathrm{V}} = -16.3$ mag, which is comparable to or rather fainter than that of SMC.

The transient was also imaged in the J and K bands by UKIRT/WFCAM on 15 April 2005, and the corresponding catalog was generated by (Hayashi et al. 2009). At the transient position, we found a point source in both the J and K bands. Although the contribution of the host galaxy is unclear in this photometry, the contamination is thought to be insignificant because the timing of the observation was close to the peak in the optical light curves (Figure 2) and the shapes on the J and K images are point-like sources while the host in the optical data is significantly extended. Furthermore, the expected magnitudes from the SED fitting of the host galaxy ($J \sim 25.5$ and $K \sim 25.2$) are more than 2 mag fainter than the photometric result of UKIRT. Therefore, the blue of the source could be originating from the transient. We also generated the SED of the transient at 88 d after the first detection with SDF data. As shown in Figure 4, the SED is significantly different from power law and well-fitted by a blackbody with a temperature of 6431 ± 310 K.

4. DISCUSSIONS

We presented detailed SDF data and photometric results of an optical transient search, which contain evidence of an unusual optical transient. Its key features are as follows: a long duration light curve; an intensive absolute magnitude (remaining brighter than -19 mag over 300 d); blue SED in NIR data around the first detection; offset from the center of host galaxy; and a faint host galaxy. These key features suggest that the unusual transient may be unique supernova such as an ultra-luminous supernova, or a peculiar supernova with type IIn spectral features. Below, we discuss differences from AGN and a tidal diruption flares and possibilities of these two supernova cases.

AGN origin is unlikely due to the offset from the center of host galaxy. In addition, the large amplitude of the transient also support this. Because typical amplidude of AGN variablity is less than 1 mag based on the long term SDSS observations for the Stripe 82 field (e.g. Ai et al. 2010, Butler & Bloom 2011, MacLeod et al 2012). The tidal disruption of stars by massive black holes at the centers of galaxies show the large amplitude flare at optical, UV, and X-ray wavelengths although some event showed no UV/transient emission due to a large amount of dust obscuration (Bloom et al. 2011; Burrows et al. 2011; Gezari et al. 2012). But the tidal disruption flare is also unlikely due to the offset. Besides the location in the host, the SED and temporal evolutions are also different from expectation of the tidal diruption flare at X-ray or UV wavelengths (the temperature of the inner accretion disc is $\sim 3 \times 10^5$ K).

Because the observed temperature in present case is significantly lower than that predicted for a tidal disruption, this transient is unlikely to be a typical one of that type. Strubbe & Quataert (2009) predicted that an early stage super-Eddington outflow would produce an intensive optical emission with a blackbody spectrum initially peaking at optical/UV wavelengths. The expected color evolution becomes bluer if the observation is made close to the peak wavelength, or showing no colour change if the observation is on the RayleighJeans tail. The blackbody spectrum peak at around 6500K is consistent with this prediction Strubbe & Quataert (2011). However, as shown in Figure 2, the current event shows both bluer and redder colors changing at 750 d after the first detection. This is inconsistent with the prediction.

The key features of ultra-luminous SNe are a roughly symmetric light curve, an absolute peak magnitudes of ~ -21 to -23 mag, and a faint host galaxy (a low mass and presumably a low-metallicity environment where are desirable for their massive progenitors (e.g. Stoll et al. 2011; Neill et al. 2011). Recent systematic studies by the Palomar Transient Factory, Pan-STARRS and others have identified a number of such events (e.g., Ofek et al. 2007, Pastorello et al. 2010 , Quimby et al. 2011; Chomiuk et al. 2011). To compare the present case with ultra-luminous SNe, we plotted the light curves of SN2010gx (Pastorello et al. 2010), SCP06F6 (Barbary et al. 2009), SN2006gy (Smith et al. 2007), and SN2008es (Miller et al. 2009; Gezari et al. 2009b) together with that of the current event. Here, we note that former two events have no obvious evidence of circumstellar interaction, SN2006gy show it, and SN2008es has implications. Figure 5 shows clear differences in absolute magnitude ($2-3$ mag fainter) and duration ($2-3$ times longer). The current event is therefore unlikely to be of ultra-luminous SNe origin.

The third possibility is that the observed transient is an SNe with type IIn spectral features. Such events are still rarely observed, but the number of detections is increasing. Figure 5 shows the light curves of SN1997cy (Germany et al. 2000; Turatto et al. 2000), SN2003ma (Rest et al. 2011), SN2005kd (Tsvetkov 2008), and SN2008iy (Miller et al. 2010). All 4 events show extremely long ($>\sim$ 400 d) durations. For SN2008iy, additional data points were collected from the 3π-survey of Pan-STARRS1 (Kaiser et al. 2010). This was because the time coverage of the data available from literature was insufficiently long to allow a comparison with the current event. The survey successfully detected the late phase (490$\sim$1000 d after the peak) of SN2008iy in i_{P1} and z_{P1} band (Tonry et al. 2012). Besides SN2003ma, the temporal evolution of the current event resembles those of SN1997cy, SN2005kd and SN2008iy in the temporal breaks at around $\sim 300-500$ d in the rest frame. The linear decline rates of SN1997cy and SN2005kd before and after the break of these events are commonly $\sim$ 0.65 mag/100 d and $\sim$ 1.5 mag/100 d, respectively. The latter is faster than the expected rate of decline for radioactive ^{56}Co (0.98 mag/100 d). Although the temporal duration of the current event is comparable to those of peculiar SNe, there are significant differences in the decline rates. The linear decay rates of SDF-05M05 in the i'-band before and after the temporal break are 0.28 mag/100 d and 0.76/100 d, respectively. These decline rates are all slower than the expected rate of the decline for radioactive ^{56}Co. SN2008iy has a decline rate similar to that of SDF-05M05. However, the broad-band SED of the current transient is well fitted by the single-temperature blackbody model, whereas that of SN2008iy deviates from the blackbody and is more like that of usual type IIn event (Miller et al. 2010). As shown in Figure 4, this broad-band SED property is also another significant differences between SN type IIn and SDF-05M05. In addition, the temperature was lower than that of Type IIn SN2003ma and SN2008am, which had blackbody spectrum (Rest et al. 2011; Chatzopoulos et al. 2011). Although we cannot entirely rule out the possibility of this event being of peculiar SNe-IIn origin because of unclear common properties of peculiar-IIn events, the current energetic event may be a new type of optical transient altogether.

All of these luminous optical transients are found in faint host galaxies. Although this may be due to selection bias, the characteristics of the host galaxies are crucial to an understanding of the origins and occurrence rates of the transients. Considering to the luminosity function of various types of galaxies (e.g Zucca et al. 2006), the fraction of faint galaxies, such as the host galaxy of SDF-05M05, is expected to increase with redshift. Zucca et al. (2006) used the same 4 CWW galaxy templates used for the photometric redshift in the present study. This may make detections of luminous events rare in nearby Universe but common at higher redshift (e.g., $z >\sim 0.5$). The apparent magnitudes at higher redshift will be fainter than 22-23 mag as same as in the current event. The limiting magnitudes of the medium deep survey of Pan-STARRS is comparable with the maximum brightness of the current event. Hence, it is expected that Pan-STARRS has been detecting numbers of these long and luminous optical transients associated with faint host galaxies. However, a slow evolution and the presence of a faint host galaxy make it difficult to classify these events as real optical transients. Therefore, coordinated long-term monitoring with larger-aperture telescopes is needed to better determine their origins. In such work, the planned strategic survey with a time-domain-survey cadence using the new wide-field imager, Hyper-Suprime-Cam attached to Subaru will prove invaluable.

This work is supported by grants NSC 100-2112-M-008-007-MY3 (YU), 99-2112-M-002-002-MY3 (KYH) and the Grant-in-Aid for Scientific Research (19540238) from the JSPS of Japan. The United Kingdom Infrared Telescope is operated by the Joint Astronomy Centre on behalf of the Science and Technology Facilities Council of the U.K. Use of the UKIRT 3.8-m telescope for the observations is supported by NAOJ. The PS1 Surveys have been made possible through contributions of the Institute for Astronomy, the University of Hawaii, the Pan-STARRS Project Office, the Max-Planck Society and its participating institutes, the Max Planck Institute for Astronomy, Heidelberg and the Max Planck Institute for Extraterrestrial Physics, Garching, The Johns Hopkins University, Durham University, the University of Edinburgh, Queen's University Belfast, the Harvard-Smithsonian Center for Astrophysics, and the Las Cum-

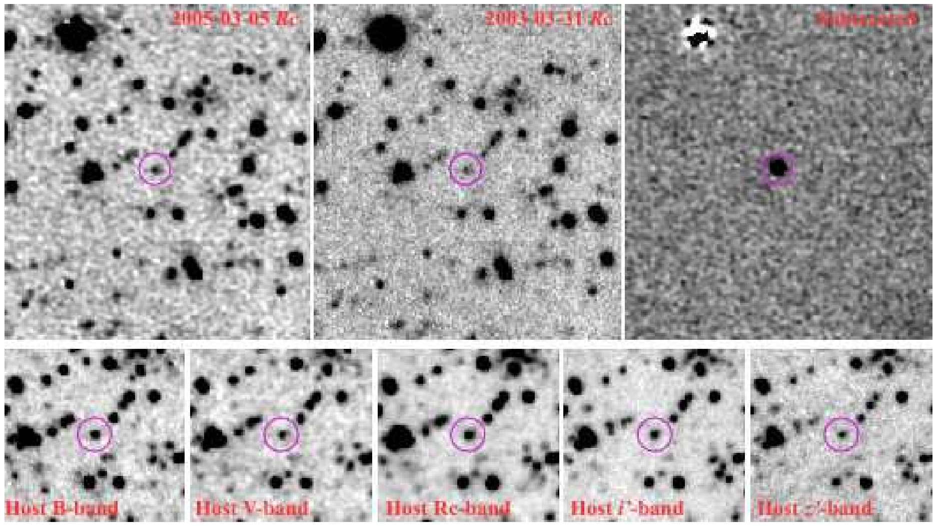

FIG. 1.— The upper panel indicates the discovery of SDF-05M05. The left image shows the first detection of SDF-05M05 on 5 March 2005. Using the image taken on 31 March 2003 (center), we generated the PSF-matched subtracted image (right). The subtracted image shows the SDF-05M05 clearly. The bottom panel shows the host galaxy of SDF-05M05 in the B, V, Rc i', and z' bands. These images were generated excluding the transient component.

bres Observatory Global Telescope Network, Incorporated, the National Central University of Taiwan, and the National Aeronautics and Space Administration under Grant No. NNX08AR22G issued through the Planetary Science Division of the NASA Science Mission Directorate.

REFERENCES

Ai, Y. L., Yuan, W., Zhou, H. Y., et al. 2010, ApJ, 716, L31
Alard, C., & Lupton, R. H. 1998, ApJ, 503, 325
Barbary, K., Dawson, K. S., Tokita, K., et al. 2009, ApJ, 690, 1358
Bloom, J. S., Giannios, D., Metzger, B. D., et al. 2011, Science, 333, 203
Bolzonella, M., Miralles, J.-M., & Pelló, R. 2000, A&A, 363, 476
Burrows, D. N., Kennea, J. A., Ghisellini, G., et al. 2011, Nature, 476, 421
Butler, N. R., & Bloom, J. S. 2011, AJ, 141, 93
Cenko, S. B., Krimm, H. A., Horesh, A., et al. 2012, ApJ, 753, 77
Chatzopoulos, E., Wheeler, J. C., Vinko, J., et al. 2011, ApJ, 729, 143
Chomiuk, L., Chornock, R., Soderberg, A. M., et al. 2011, ApJ, 743, 114
Christensen, L., Hjorth, J., & Gorosabel, J. 2004, A&A, 425, 913
Drake, A. J., Djorgovski, S. G., Mahabal, A., et al. 2011, ApJ, 735, 106
Gal-Yam, A., Mazzali, P., Ofek, E. O., et al. 2009, Nature, 462, 624
Germany, L. M., Reiss, D. J., Sadler, E. M., Schmidt, B. P., & Stubbs, C. W. 2000, ApJ, 533, 320
Gezari, S., Heckman, T., Cenko, S. B., et al. 2009, ApJ, 698, 1367
Gezari, S., Halpern, J. P., Grupe, D., et al. 2009, ApJ, 690, 1313
Gezari, S., Chornock, R., Rest, A., et al. 2012, Nature, 485, 217
Hayashi, M., Motohara, K., Shimasaku, K., et al. 2009, ApJ, 691, 140
Huang, K. Y., Urata, Y., Tung, Y. H., et al. 2012, ApJ, 748, 44
Kaiser, N., W. Burgett, K. Chambers, L. Denneau, J. Heasley, . Jedicke, E. Magnier, J. Morgan, P. Onaka, and J. Tonry, 2010, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, volume 7733 of Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series.
Kashikawa, N., Shimasaku, K., Yasuda, N., et al. 2004, PASJ, 56, 1011
Levan, A. J., Tanvir, N. R., Cenko, S. B., et al. 2011, Science, 333, 199
Ly, C., Malkan, M. A., Hayashi, M., et al. 2011, ApJ, 735, 91
Ly, C., Malkan, M. A., Treu, T., et al. 2009, ApJ, 697, 1410
MacLeod, C. L., Ivezić, Ž., Sesar, B., et al. 2012, ApJ, 753, 106
Miller, A. A., Chornock, R., Perley, D. A., et al. 2009, ApJ, 690, 1303
Miller, A. A., Silverman, J. M., Butler, N. R., et al. 2010, MNRAS, 404, 305
Motohara, K., Hayashi, M., Shimasaku, K., et al. 2008, Panoramic Views of Galaxy Formation and Evolution, 399, 274
Neill, J. D., Sullivan, M., Gal-Yam, A., et al. 2011, ApJ, 727, 15
Ofek, E. O., Cameron, P. B., Kasliwal, M. M., et al. 2007, ApJ, 659, L13
Ouchi, M., Shimasaku, K., Okamura, S., et al. 2004, ApJ, 611, 660
Pastorello, A., Smartt, S. J., Botticella, M. T., et al. 2010, ApJ, 724, L16
Quimby, R. M., Kulkarni, S. R., Kasliwal, M. M., et al. 2011, Nature, 474, 487
Rest, A., Foley, R. J., Gezari, S., et al. 2011, ApJ, 729, 88
Rhoads, J. E. 2001, ApJ, 557, 943
Smith, N., Li, W., Foley, R. J., et al. 2007, ApJ, 666, 1116
Stoll, R., Prieto, J. L., Stanek, K. Z., et al. 2011, ApJ, 730, 34
Strubbe, L. E., & Quataert, E. 2011, MNRAS, 415, 168
Strubbe, L. E., & Quataert, E. 2009, MNRAS, 400, 2070
Tanaka, M., Moriya, T. J., Yoshida, N., & Nomoto, K. 2012, MNRAS, 2797
Tonry, J. L., Stubbs, C. W., Lykke, K. R., et al. 2012, ApJ, 750, 99
Totani, T., & Panaitescu, A. 2002, ApJ, 576, 120
Tsvetkov, D. Y. 2008, Peremennye Zvezdy, 28, 6
Turatto, M., Suzuki, T., Mazzali, P. A., et al. 2000, ApJ, 534, L57
Turatto, M., Cappellaro, E., Danziger, I. J., et al. 1993, MNRAS, 262, 128
Urata, Y., Huang, K., Yamaoka, K., Tsai, P. P., & Tashiro, M. S. 2012, ApJ, 748, L4
Urata, Y., Huang, K., Im, M., et al. 2009, ApJ, 706, L183
van Velzen, S., Farrar, G. R., Gezari, S., et al. 2011, ApJ, 741, 73
Zauderer, B. A., Berger, E., Soderberg, A. M., et al. 2011, Nature, 476, 425
Zucca, E., Ilbert, O., Bardelli, S., et al. 2006, A&A, 455, 879

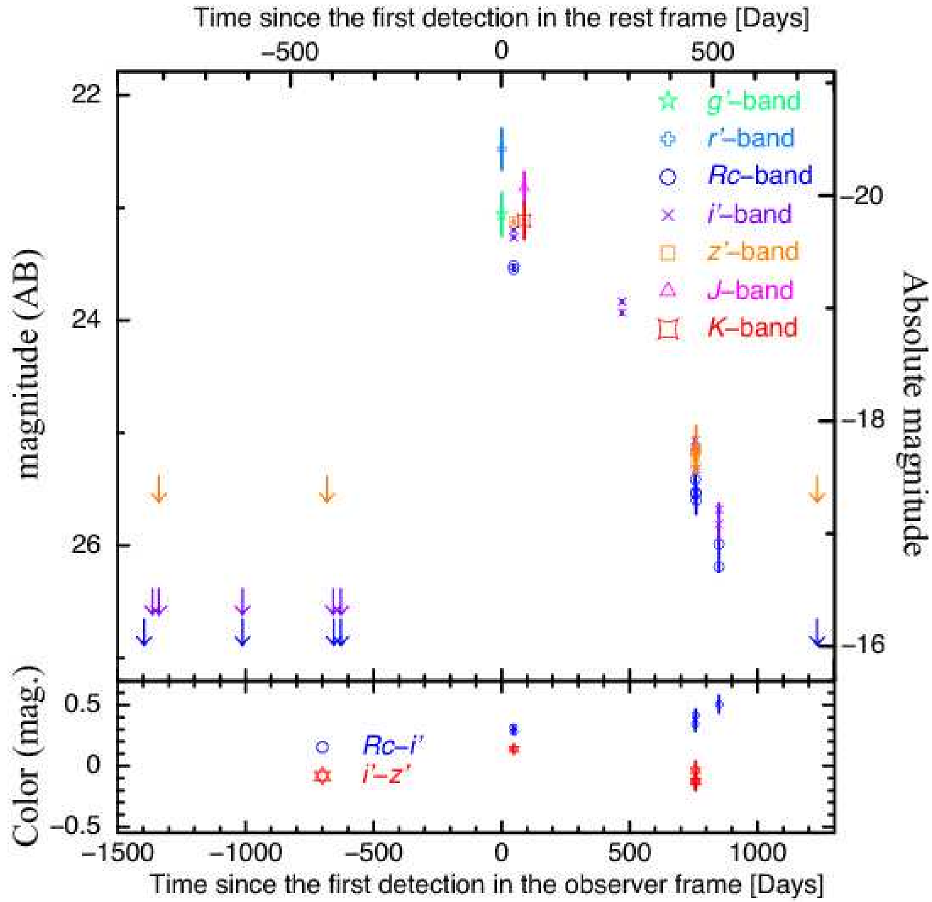

FIG. 2.— Light curves and temporal color evolution of SDF-05M05. SDF-05M05 maintained a magnitude brighter than −19 mag for approximately 300 d in the rest frame, a period significantly longer than for typical SNe or ultra-luminous SNe.

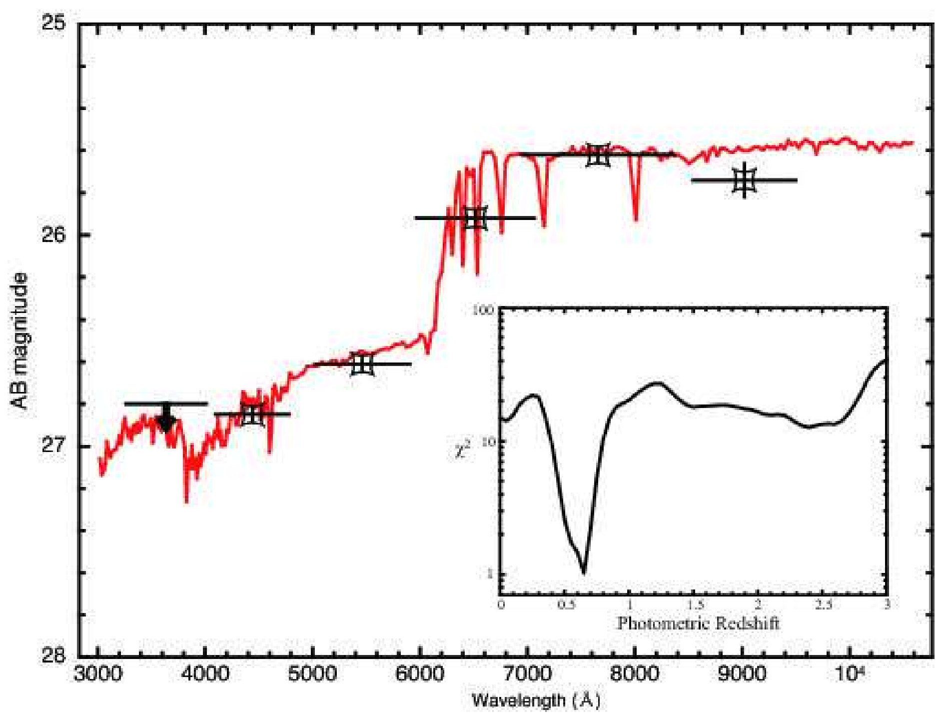

FIG. 3.— The measured $BVRci'z'$ band fluxes of the SDF-05M05 host galaxy (data points), compared with the best-fit template SED (starburst type) for $z = 0.65$ (solid curves). The sub panel shows the reduced chi-square of the model fit to the multi-band photometric data of the host galaxy, shown as a function of the assumed redshift.

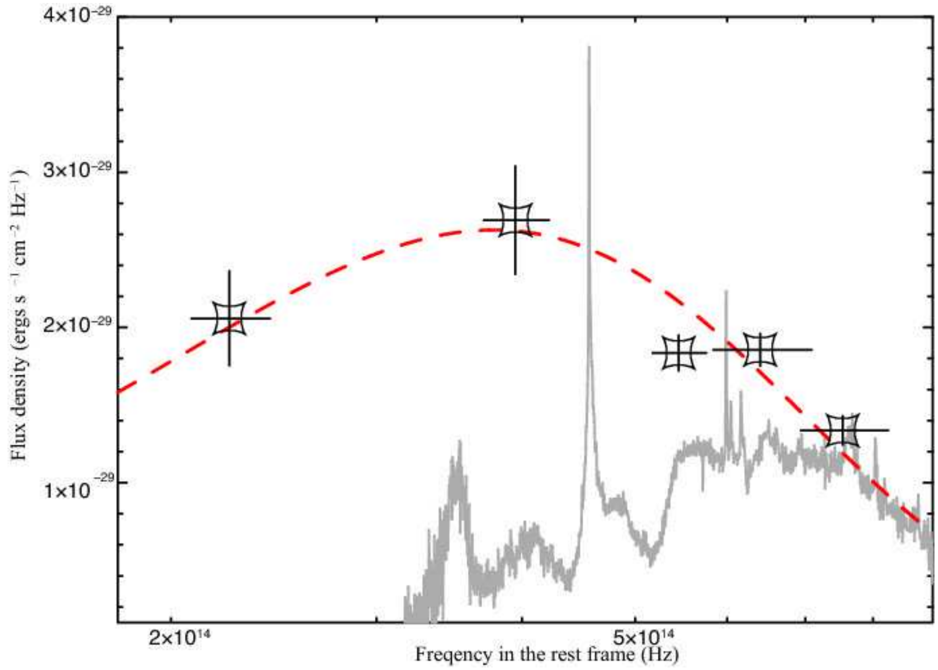

FIG. 4.— The spectral energy distribution of the transient at $T_0 + 88$ d. The SED is well fitted by the single-temperature blackbody model as described with a dashed line. Box points show the photometric results of the SDF-05M05. For the spectral shape comparison, solid line show the arbitrarily scaled broadband spectrum of SN1997cy at 84 d after the peak.

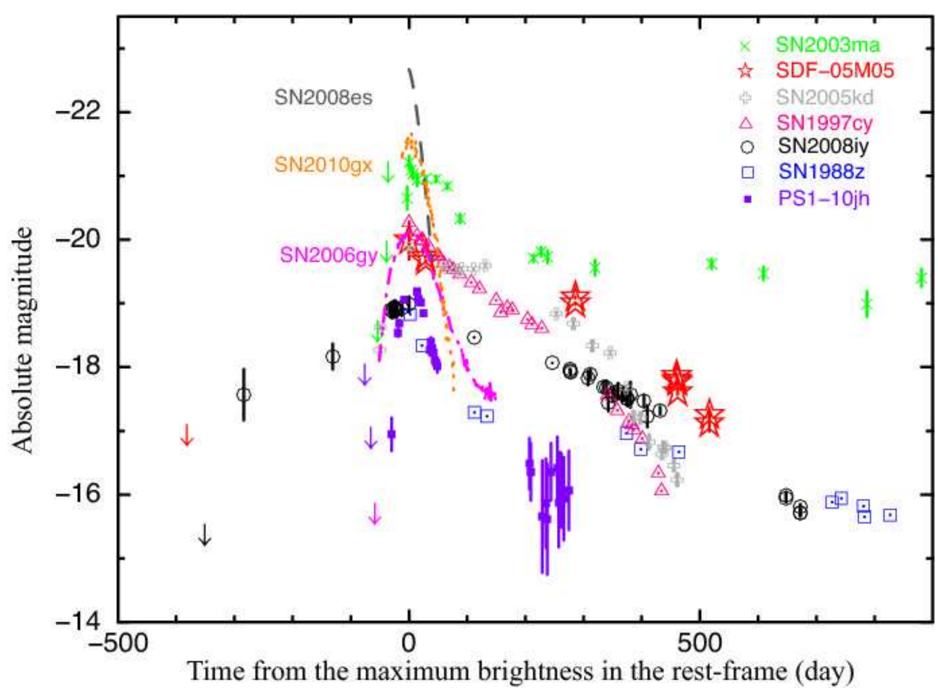

FIG. 5.— Absolute light curve of SDF-05M05 compared to those of tidal disruption flare (PS1-10jh; Gezari et al. (2012)), ultra-luminous supernova and peculiar SNIIn. For ultra-luminous supernova, lines indicate the light curves of SN2008es (Miller et al. 2009; Gezari et al. 2009b), SN2010gx (Pastorello et al. 2010), and SN2006gy (Smith et al. 2007). For peculiar SNIIn, points as labeled show the temporal evolutions of SN1988Z (Turatto et al. 1993), SN1997cy (Germany et al. 2000; Turatto et al. 2000), SN2003ma (Rest et al. 2011), SN2005kd (Tsvetkov 2008), and SN2008iy (Miller et al. 2010).